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AERODYNAMIC CHARACTERISTICS OF BALLUTES AND HEMISFLO PARACHUTES AT MACH NUMBERS OF 2.5, 2.6, AND 2.9

Lawrence L. Galigher

ARO, Inc.

May 1965

PROPULSION WIND TUNNEL FACILITY

ARNOLD ENGINEERING DEVELOPMENT CENTER

AIR FORCE SYSTEMS COMMAND

ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

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BALLUTES AND HEMISFLO PARACHUTES AT
MACH NUMBERS OF 2.5, 2.6, AND 2.9

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FOREWORD

The work reported herein was done at the request of and for the Air Force Flight Dynamics Laboratory (AFFDL), Research and Technology Division (RTD), Air Force Systems Command (AFSC), under Program Element 62405364/6065.

The results of the test were obtained by ARO, Inc. (a subsidiary of Sverdrup and Parcel, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), AFSC, Arnold Air Force Station, Tennessee, under Contract AF40(600)-1000. The test was conducted from April 2 to 6, 1965 under ARO Project No. PS0552, and the report was submitted by the author on May 6, 1965.

This technical report has been reviewed and is approved.

Francis M. Williams
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Colonel, USAF
DCS/Test

ABSTRACT

A test was conducted in the 16-ft supersonic tunnel to obtain drag, inflation, and stability characteristics of a metal ballute, a cloth ballute, and three hemisflo parachutes (5-, 10-, and 15-percent porosity). The cloth and metal ballutes were investigated at Mach numbers of 2.5 and 2.9, respectively, at a dynamic pressure of 120 psfa. The hemisflo parachutes were investigated at a Mach number of 2.6 at a dynamic pressure of 120 psfa. The drag coefficient of the hemisflo parachutes decreased as canopy porosity increased. There was no discernible effect of canopy porosity on stability of the parachutes.

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ILLUSTRATIONS

TABLE

NOMENCLATURE

C_{D_O} Decelerator drag coefficient, $\dfrac{F_D}{q_\infty S_O}$

d   Base diameter of strut-mounted centerbody, 1.467 ft

F_D Decelerator drag force, lb

M_∞ Free-stream Mach number

q_∞ Free-stream dynamic pressure, psfa

S_O Decelerator drag-producing area
                a. Cloth ballute, 28.2753 ft^2
                b. Hemisflo parachute, 28.2753 ft^2

x   Distance aft of centerbody base plane to confluence
               point of decelerator
                a. Cloth ballute, 8.15 ft
                b. Hemisflo parachute, 2.83 ft

SECTION I
INTRODUCTION

A test was conducted in the Propulsion Wind Tunnel, Supersonic (16S) to determine the steady-state drag, inflation, and stability characteristics of two types of aerodynamic decelerators in supersonic flow. The decelerators investigated during this test were conical ballutes and hemisflo parachutes. A cloth ballute and a metal ballute were tested at nominal Mach numbers of 2.5 and 2.9, respectively, at a nominal free-stream dynamic pressure of 120 psfa. Three hemisflo parachute configurations were tested at a nominal Mach number and free-stream dynamic pressure of 2.6 and 120 psfa, respectively.

SECTION II
APPARATUS

2.1 TEST FACILITY

Tunnel 16S is a closed-circuit, continuous flow wind tunnel currently capable of operating at Mach numbers from 1.65 to 3.20. The tunnel is capable of operating over a stagnation pressure range from 100 to approximately 1600 psfa. The test section stagnation temperature can be controlled through the range of 100 to 650°F. The wind tunnel specific humidity is controlled by removing tunnel air and supplying make-up air from an atmospheric dryer. A complete description of the facility and its operating characteristics are contained in the Test Facilities Handbook.[1]

2.2 TEST ARTICLE

2.2.1 Model Centerbody and Deployment System

The decelerators tested during this investigation were deployed from a strut-mounted centerbody. Dimensions of the centerbody are presented in Fig. 1, and the location of the centerbody in the wind tunnel is shown in Fig. 2. The wind tunnel installation of the centerbody is shown in Fig. 3.

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[1]Test Facilities Handbook, (5th Edition). "Propulsion Wind Tunnel Facility, Vol. 3." Arnold Engineering Development Center, July 1963.

The ballutes were packed in the aft end of the centerbody and deployed with a drogue parachute. The hemisflo parachutes were packed in the aft end of the centerbody on a spring-loaded plate and were held against the plate by retaining straps. The retaining straps were released by a squib-fired release pin mechanism. A three-quarter rear view of a hemisflo parachute packed in the aft end of the centerbody is shown in Fig. 4. The ballute riser line was affixed to the centerbody by a cable with a load cell in series; the parachute riser line was similarly affixed to the centerbody, but a swivel was used to prevent twisting of the parachute suspension lines. A shear pin, designed to protect the load cell, was used to connect the riser line to the cable.

2.2.2 Decelerators

The 6-ft-diam cloth ballute and the 5-ft-diam metal ballute were constructed of nylon and woven stainless steel, respectively. Both ballutes were 80-deg conical ballutes with four side-ram-air inlets. The cloth ballute had a 10-percent burble fence. No burble fence was incorporated on the metal ballute. The dimensions of the ballutes are shown in Fig. 5, and a photograph of the cloth ballute is shown as Fig. 6.

The hemisflo parachute canopies had a roof and skirt constructed of 0.75-in.-wide nylon ribbons and 16-in.-wide solid nylon mesh, respectively. The riser lines and suspension lines were also of nylon construction. The hemisflo parachute configurations are identified by nominal diameter and canopy geometric porosity. Nominal diameter is defined as the diameter of a circle having the same total area as the total area of the drag-producing surface, which includes all openings in the drag-producing surface such as slots and vents. Geometric porosity is defined as the ratio of the open area of a drag-producing surface to the total canopy drag-producing surface area. The parachutes had a nominal diameter of 6 ft and a suspension line length (skirt to confluence point) of 12 ft. The riser line length was 2.83 ft. The hemisflo parachutes had geometric porosities of 5, 10, and 15 percent. Details of the parachutes are shown in Fig. 7, and a photograph of one of the hemisflo parachutes is shown as Fig. 8.

2.3 INSTRUMENTATION

Double element load cells of 10,000- and 5,000-lb capacity were used to measure the drag load of the ballutes and hemisflo parachutes, respectively. A direct writing oscillograph was used to monitor the decelerator drag load during testing. Five movie cameras and two television cameras, installed in the test section walls, were used to document and monitor these tests.

SECTION III
PROCEDURE

A decelerator was packed in the aft end of the strut-mounted center-body before initiation of wind tunnel test operations. Once test conditions were established, the decelerator was ejected from the centerbody into the airstream. Motion pictures and dynamic drag data were obtained during and after each deployment. Upon completion of the decelerator deployment sequence, a steady-state drag load was calculated by averaging the analog output signal from the strain-gage load cell over a 1-sec interval.

The cloth ballute and the metal ballute were deployed at nominal Mach numbers of 2.5 and 2.9, respectively, at a free-stream dynamic pressure of 120 psfa. The three hemisflo parachutes were deployed at a nominal Mach number of 2.6 at a free-stream dynamic pressure of 120 psfa. The centerbody was maintained at zero angle of attack and yaw for the entire test. A complete summary of the test conditions is presented in Table I.

The accuracy of the drag load obtained from the 5,000- and 10,000-lb capacity load cells was determined to be $F_D = \pm 9$ lb for the range of drag loads measured during these tests.

SECTION IV
RESULTS AND DISCUSSION

A limited amount of steady-state drag data was obtained during this test because of failure of the decelerators during or shortly after inflation. The failure of the metal ballute was caused by a malfunction of one of the four side-air inlets during the ballute inflation process. The sudden change in tunnel flow blockage created by the fully inflated cloth ballute caused a "tunnel flow breakdown" and subsequently, loss of the ballute. The cloth ballute was fully inflated for approximately 1 sec before tunnel flow breakdown. The three hemisflo parachute failures were caused by separation of several suspension lines from the confluence point approximately 12 sec after inflation. The parachutes inflated fully, and steady-state data were obtained before failure of the suspension lines. A complete summary of the test results is given in Table I.

4.1 DEPLOYMENT LOADS

Deployment of trailing aerodynamic decelerators generally creates two forces known as "snatch force" and "opening shock force." For wind tunnel testing of decelerators, the snatch force is defined as that force imposed on the centerbody by the deceleration of the mass of the decelerator from its velocity at line extension to zero velocity relative to the centerbody. The snatch force is followed closely by the opening shock force, which is defined as that force imposed on the centerbody by the sudden inflation of the decelerator at full line extension.

The snatch force and the opening shock force were found to vary considerably during each parachute deployment since they are a function of the parachute packing procedure. The snatch and opening shock forces for the parachutes varied between 1250 and 3500 lb, and 815 and 2560 lb, respectively. The snatch force for the cloth and metal ballutes was 1375 and 875 lb, respectively. The ballutes did not exhibit an opening shock force because a finite amount of time is required for the ballute inflation process. The deployment-time histories of the decelerators are shown in Fig. 9 for each of the deployments.

4.2 STEADY-STATE LOADS

As shown in Fig. 10, the drag coefficient of the hemisflo parachutes decreases with increasing canopy geometric porosity. Decreasing the porosity from 15 to 5 percent increases the drag coefficient approximately 27 percent.

The drag coefficient of the cloth ballute was 0.626 at $M_\infty = 2.5$. No steady-state drag data were obtained for the metal ballute since it failed during the inflation process.

4.3 INFLATION AND STABILITY CHARACTERISTICS

Photographic coverage obtained by movie cameras permitted the determination of decelerator inflation and stability characteristics. Analysis of the motion pictures indicates that the cloth ballute attained full inflation approximately 1.5 sec after initiation of deployment and that the fully inflated ballute exhibited no oscillation in a plane perpendicular to the riser line axis.

The hemisflo parachutes attained full canopy inflation during each deployment and exhibited approximately ±2.5 ft of oscillation in a plane

that is perpendicular to the riser line axis and parallel to the canopy vent cap. There was no discernible effect of canopy geometric porosity on the severity of the oscillation.

SECTION V
CONCLUDING REMARKS

Tests were conducted to obtain drag, inflation, and stability characteristics of a nylon ballute, a woven stainless steel ballute, and three hemisflo parachutes having geometric porosities of 5, 10, and 15 percent. The cloth ballute, metal ballute, and hemisflo parachutes were investigated at Mach numbers of 2.5, 2.9, and 2.6, respectively, at a dynamic pressure of 120 psfa.

Failure of the metal ballute during the inflation process prevented the acquisition of any usable data. A limited amount of data was obtained for the cloth ballute and hemisflo parachutes before their subsequent failure shortly after inflation.

The cloth ballute inflated fully and exhibited very good stability. The three hemisflo parachutes inflated fully but exhibited poor stability. Analysis of the motion pictures indicates that the effect of canopy porosity on parachute stability was not discernible. The drag coefficient of the hemisflo parach · .·ː decreases as canopy geometric porosity increases.
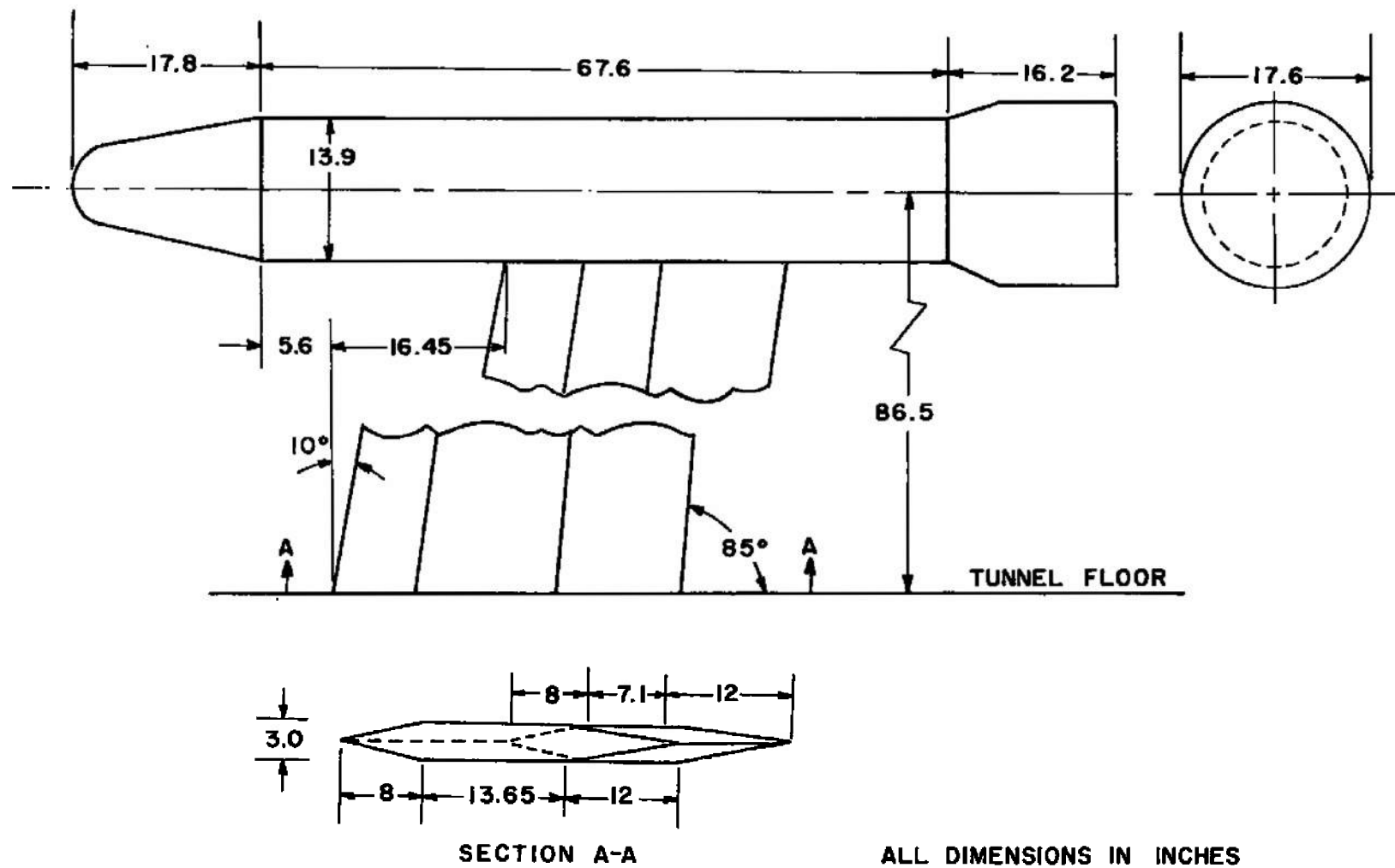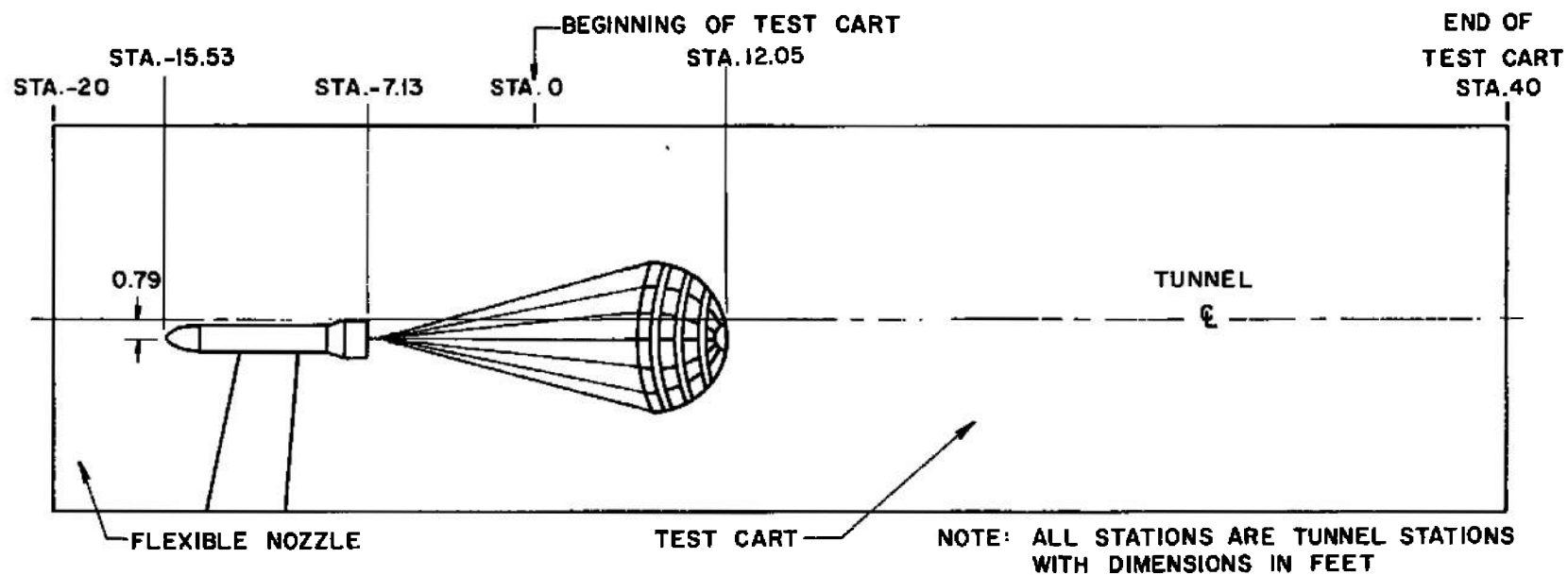
SECTION A-A   ALL DIMENSIONS IN INCHES

Fig. 1 Model Centerbody Dimensions

STA.-15.53

BEGINNING OF TEST CART
STA.12.05

END OF
TEST CART
STA.40

STA.-20

STA.-7.13

STA. 0

TUNNEL
¢L

0.79

FLEXIBLE NOZZLE

TEST CART

NOTE: ALL STATIONS ARE TUNNEL STATIONS
WITH DIMENSIONS IN FEET

a. Parachute

Fig. 2 Location of Model in Test Section

STA.-20 STA.-15.53 STA.-7.13 STA.0 BEGINNING OF TEST CART STA.1.87 STA.7.83 END OF TEST CART STA.40

0.79

TUNNEL ℄

FLEXIBLE NOZZLE TEST CART NOTE: ALL STATIONS ARE TUNNEL STATIONS WITH DIMENSIONS IN FEET
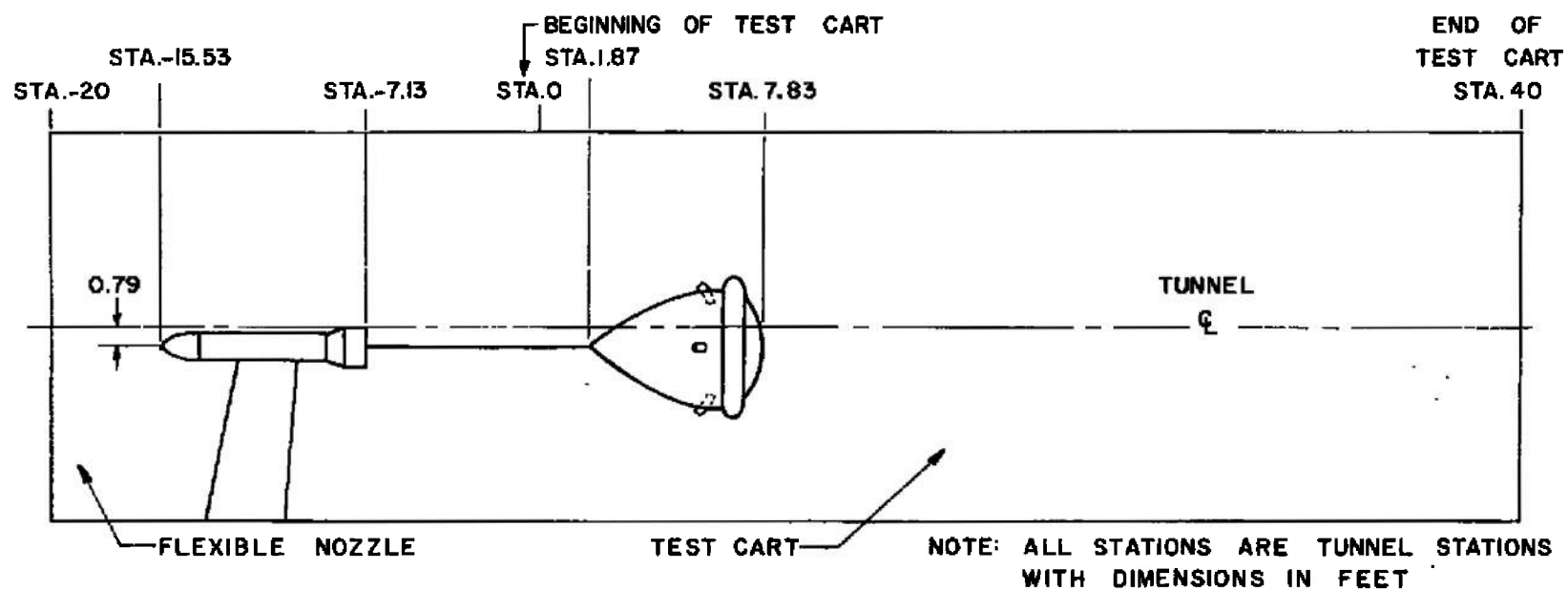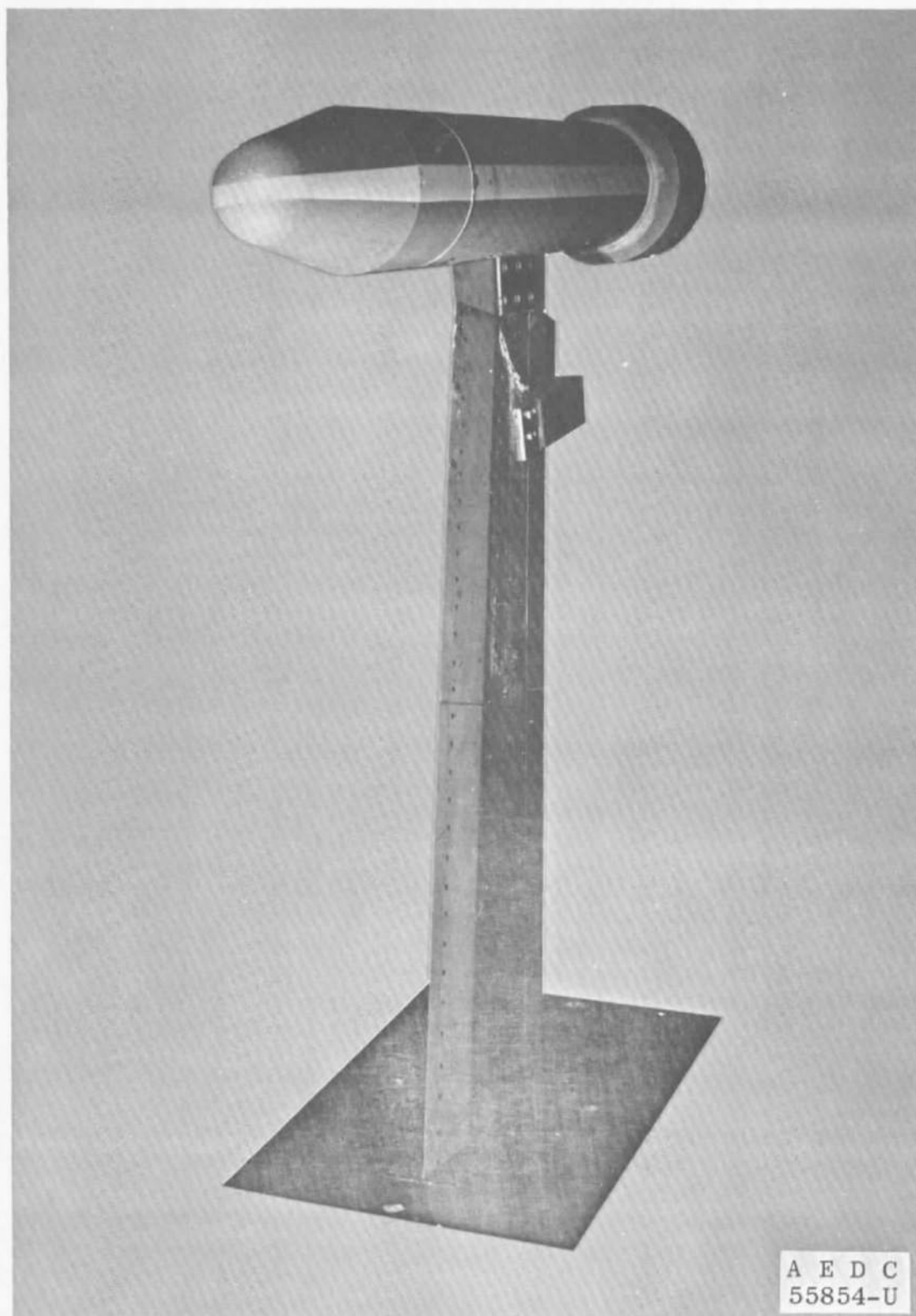
b. Ballute

Fig. 2 Concluded

Fig. 3 Installation of Model Centerbody in Test Section
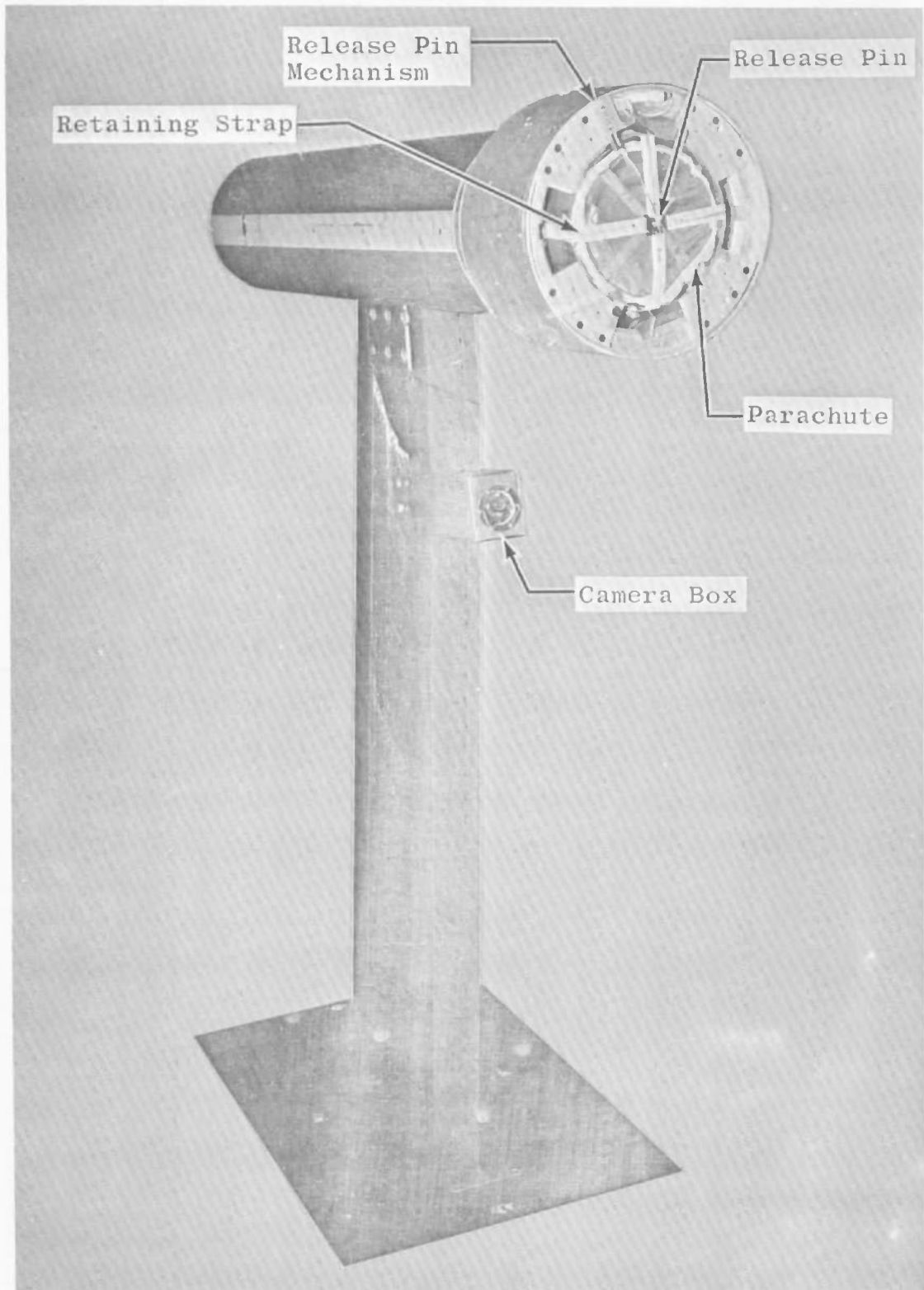
Fig. 4 Three-Quarter Rear View of Model Centerbody

30° TYPICAL (2 PLACES)

KEEPER RING

128.50

14.50

60.0
DIAM

MAX. DIAM

RISER

45°
INLET

TYPICAL (2 PLACES)

CONFLUENCE
POINT

ATTACHMENT
POINT

43.69

NOTE: ALL DIMENSIONS IN INCHES

41.69

65.815
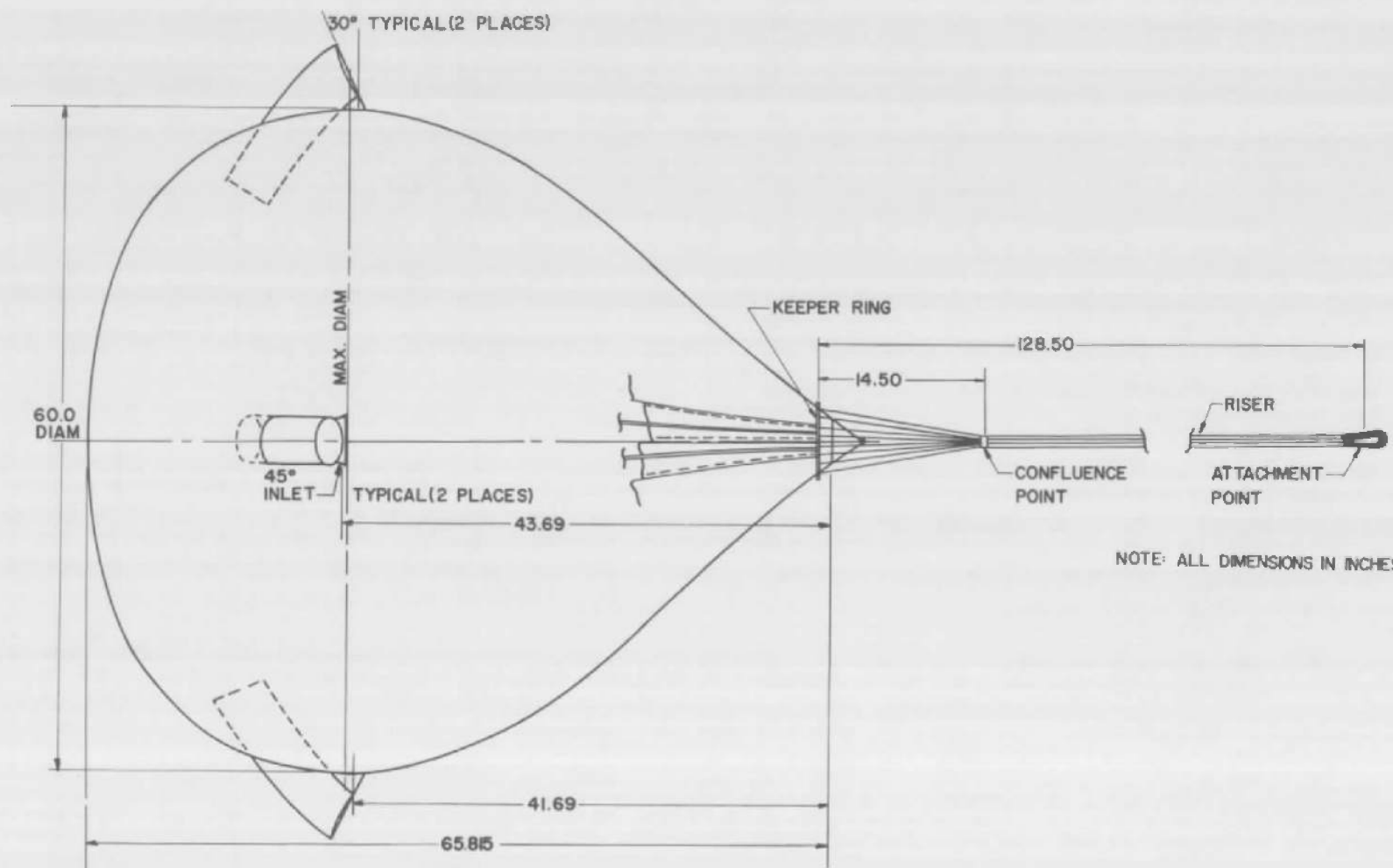
a. Metal Ballute

Fig. 5 Ballute Details
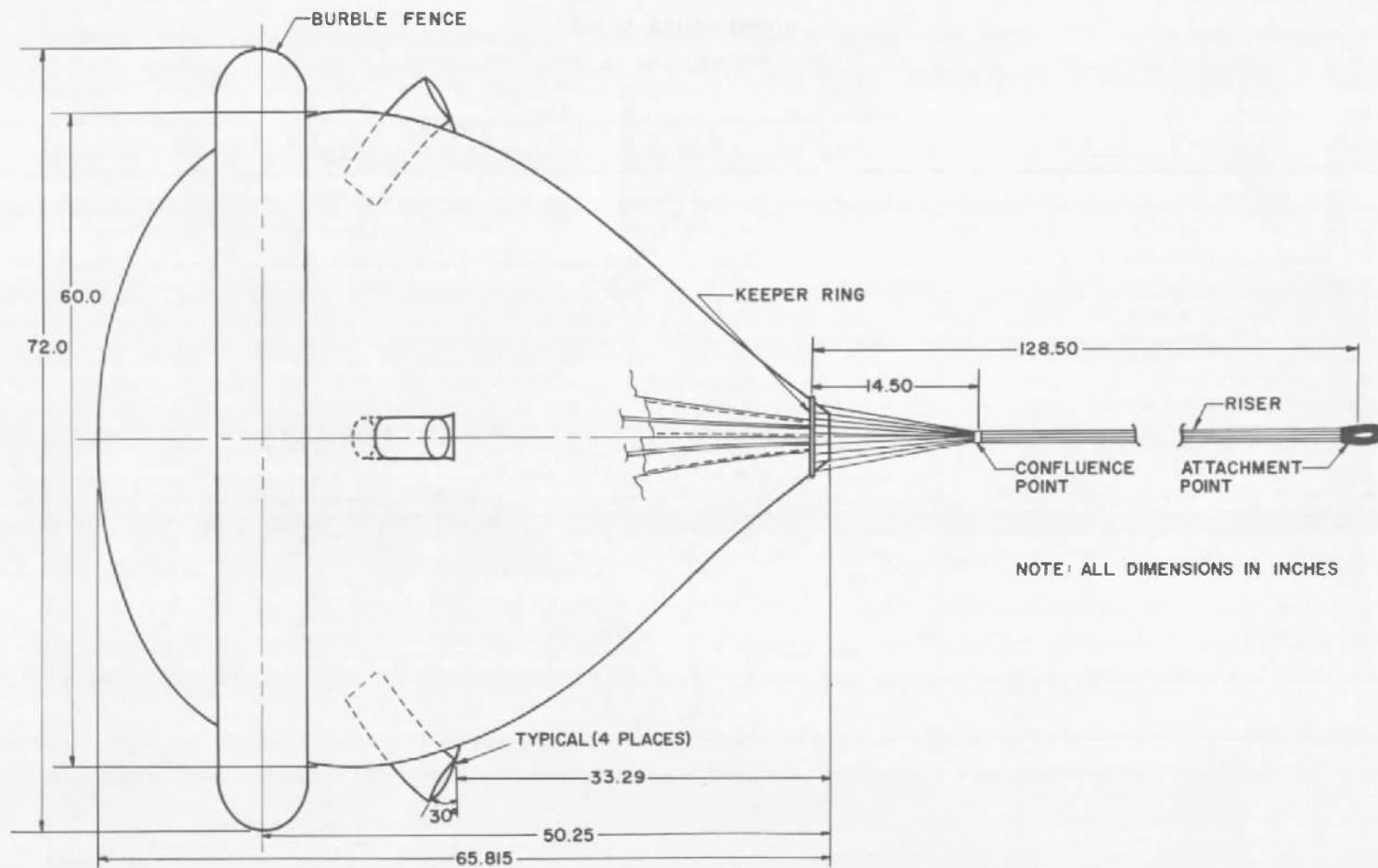
b. Cloth Ballute

Fig. 5 Concluded

Fig. 6 Cloth Ballute

HEMISFLO RIBBON
RIBBON WIDTH, 0.75 INCH
20 GORES
72 IN. NOMINAL DIAMETER
SUSPENSION LINE LENGTH, l = 144 IN.

NOTE: CROSSHATCHING
REPRESENTS CLOSED
SPACING

NOTE: ALL DIMENSIONS IN INCHES
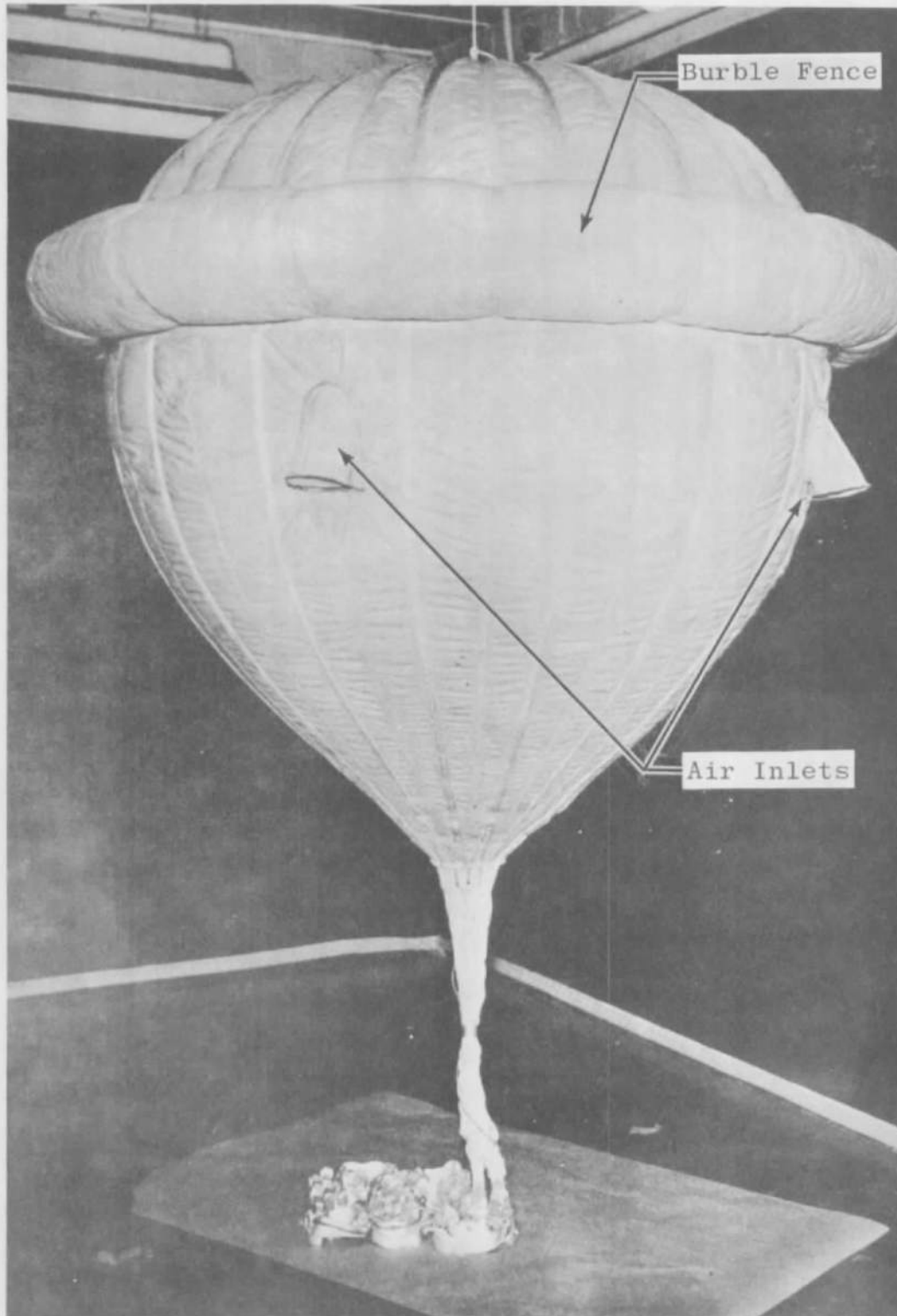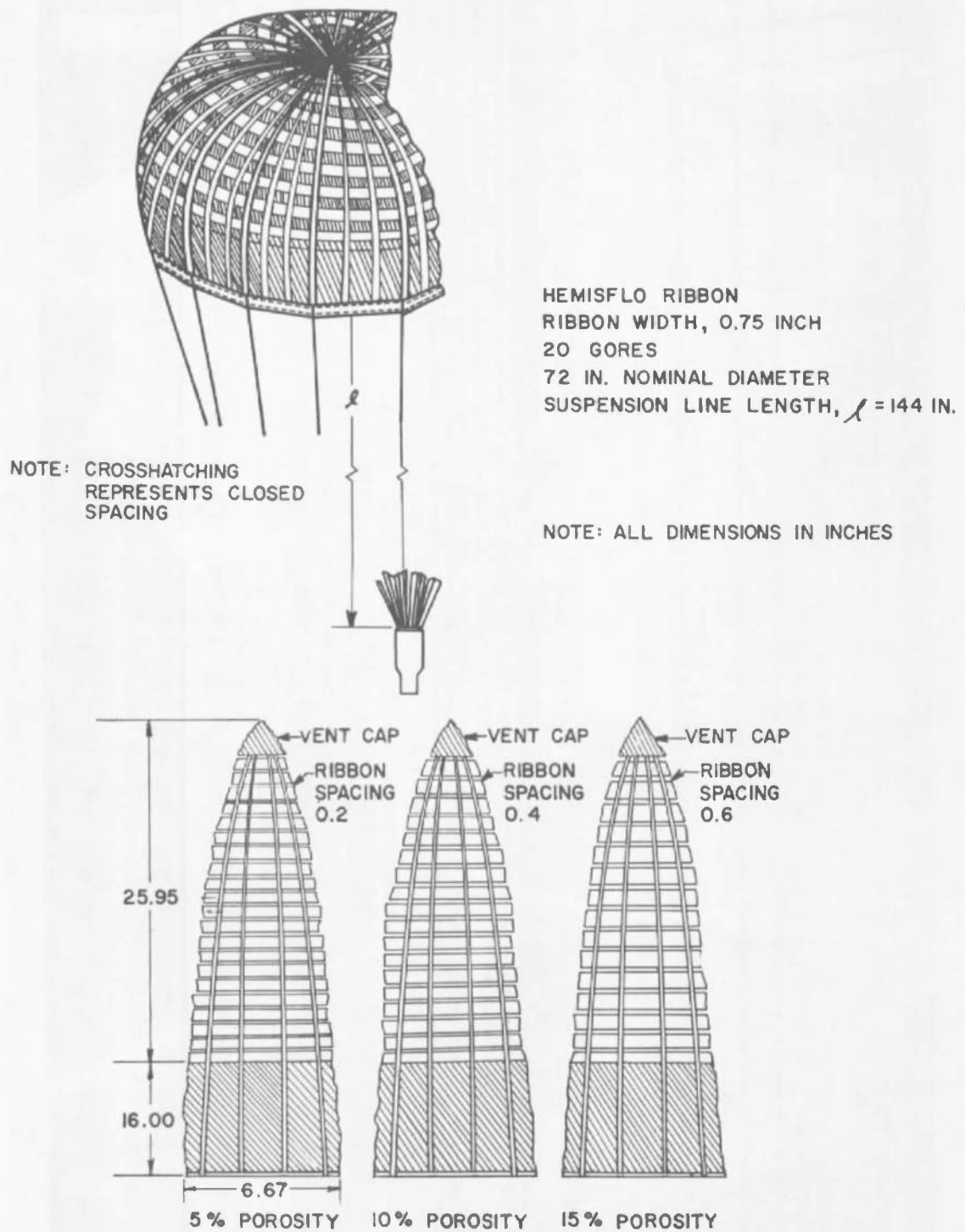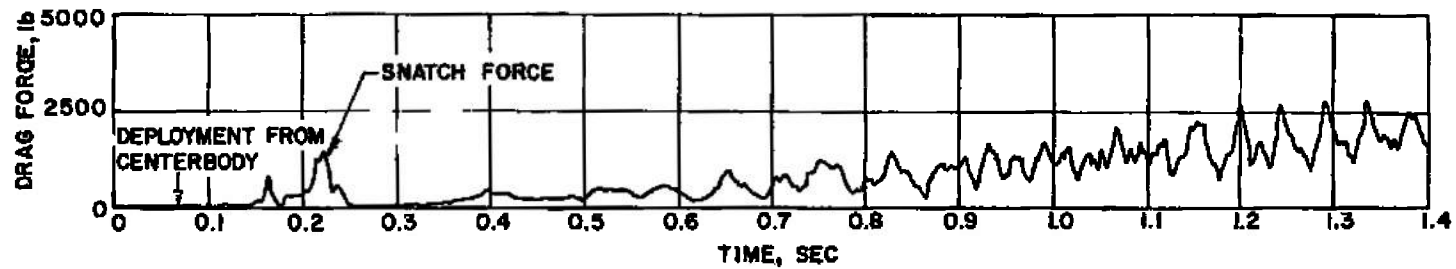
Fig. 7 Parachute Details
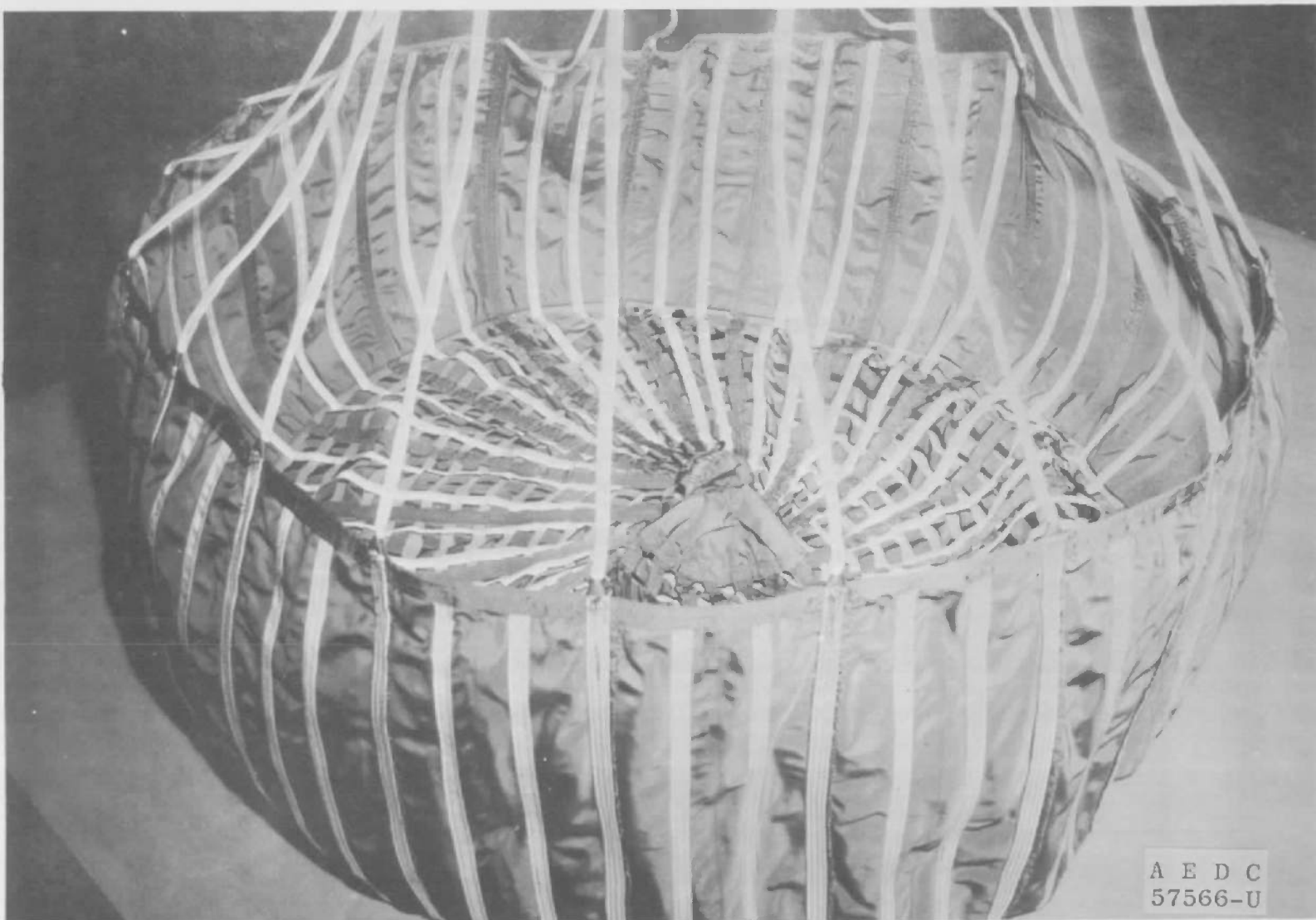
Fig. 8 Hemisflo Parachute
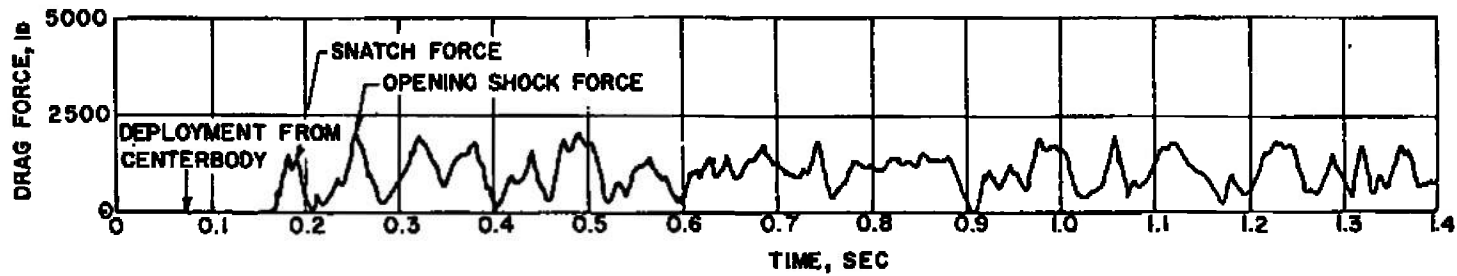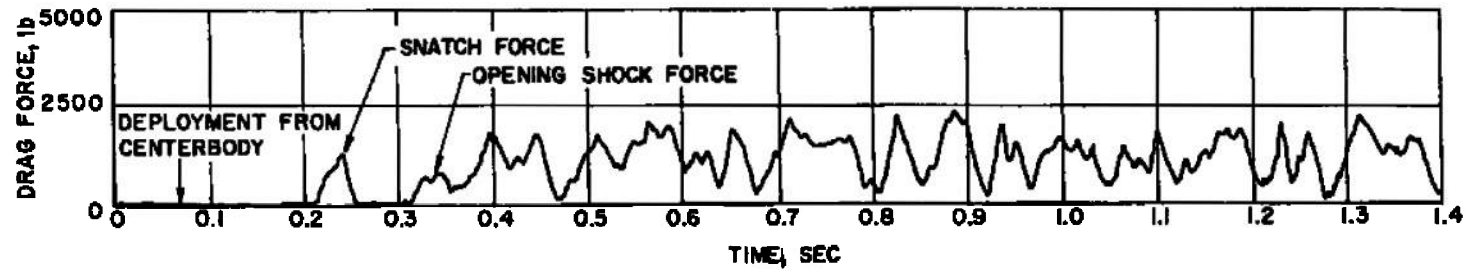
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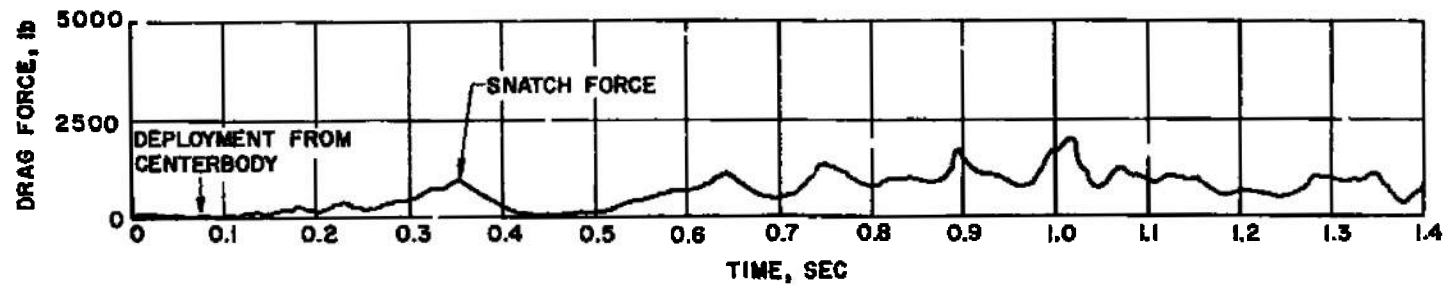
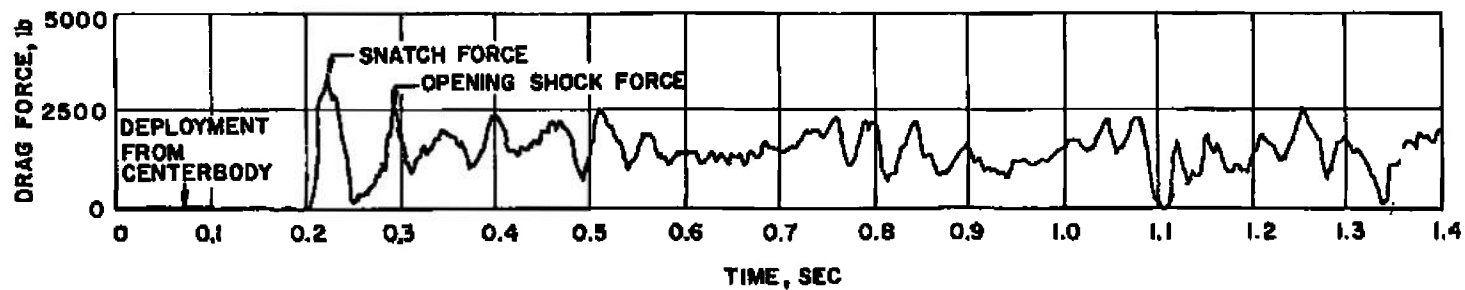a. Metal Ballute

b. Cloth Ballute

Fig. 9 Decelerator Deployment Characteristics

c. Parachute of 15-percent Porosity

d. Parachute of 10-percent Porosity

e. Parachute of 5-percent Porosity

Fig. 9 Concluded
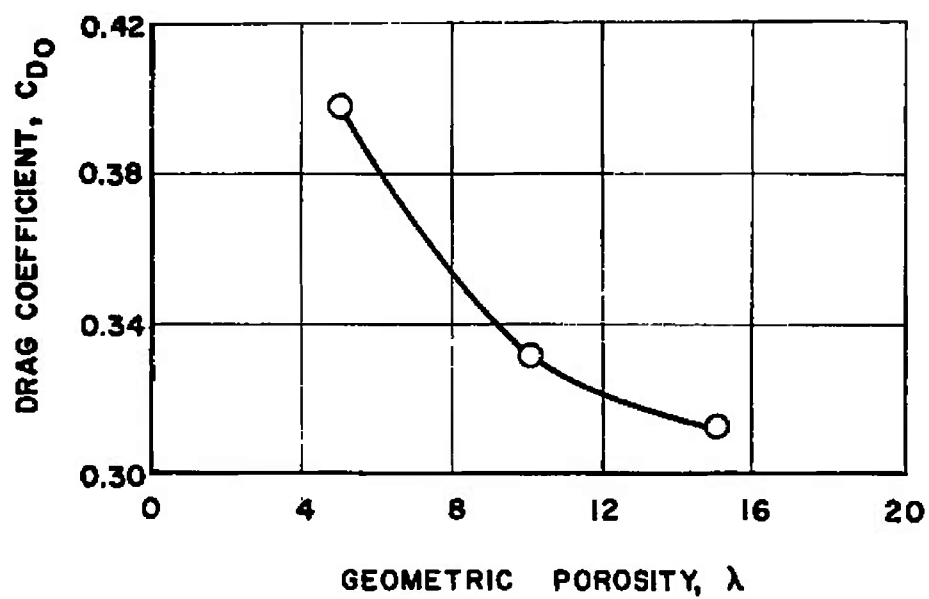
Fig. 10 Variation of Drag Coefficient with Canopy Geometric Porosity,
M_∞ = 2.6, x/d = 1.93

TABLE I
SUMMARY OF TEST CONDITIONS AND RESULTS

Configuration	M_∞	q_∞, psfa	Decelerator Diameter, ft		Canopy Geometric Porosity, percent	C_{D_O}	Remarks
			Maximum	Nominal			
Metal ballute	2.900	119.9	5		—	—	Failure of ballute during inflation process
Cloth ballute	2.500	120.0	6		—	0.626	Tunnel flow breakdown approximately 1 sec after full inflation of ballute
Hemisflo	2.596	120.2		6	15	0.313	Separation of several suspension lines from confluence point approximately 12 sec after canopy inflation.
Hemisflo	2.596	120.4		6	10	0.331	Separation of several suspension lines from confluence point approximately 12 sec after canopy inflation
Hemisflo	2.599	120.0		6	5	0.397	Separation of several suspension lines from confluence point approximately 10 sec after canopy inflation

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